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Change of Plant Nutrients in Soil and Spring Barley Depending on the Field Pea Management as a Catch Crop

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Abstract: Catch crop cultivation for green manure is considered to be a sustainable agricultural strategy whose main goal is to mitigate the negative effects of inappropriate plant sequent by increasing the soil biological activity, improving the nutrient content and reducing their loss from soil. Additionally, correct catch crop management is expected to improve the yield of consequent crops as well as their quality parameters. The effects of field pea when used as a catch crop, either incorporated in autumn or mulched and incorporated in spring vs. a control—without a catch crop on the soil chemical properties (total N, organic C, available forms of K and P) and the composition of spring barley grain and straw (total N, P, K, Ca) were studied for three years (2009 to 2011) in two-field, one-factor experiments, which were conducted on two different soil types (Luvisol and Phaeozem). The catch crop had no effect regarding the soil pH, soil organic C or total N content. In turn, applying a catch crop significantly affected the concentration of the available K (in both soils) and available P content (Phaeozem). The effect of a catch crop on the nutrients in the grain and straw of spring barley was associated with the soil type. In Luvisol, a catch crop, independent of its management, increased the total N and P in the grain and straw of spring barley. In Phaeozem, a catch crop that was incorporated in the autumn significantly increased the K content in grain.

Keywords: catch crop; grain and straw yield; nutrients; soil; spring barley

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1. Introduction

The ecological problems caused by high-intensity agriculture have become a topical issue, with a negative impact on the agroecosystem and its surrounding environment, as shown by the declining of crop and weed species diversity [1,2]. Catch crops, which are used as a source of soil organic matter in agriculture, are mainly valued in the crop rotation of cereals because they improve the set of physical [3–6], chemical and biological [7–12] soil properties. The catch crops that are cultivated for green manure also contribute to reducing the nutrient loss in soil. They are grown after the main crop because they retain the nutrients in the soil and then release them during the following growth season. In this way, they reduce the need for fertilizer and help protect the aquatic environment [13]. Cultivating catch crops mitigates the negative effects of improper crop plants succession, which generally results in an increase in grain yield [5,14,15]. The data concerning the influence of catch crop management on the soil chemical properties are ambiguous. Its impact depends on the plant being cultivated, the sowing term, the length of the growing season, weather conditions, soil properties, and finally, on the cultivation management [3]. Some research has indicated that Fabaceae might have a beneficial effect on the soil properties and yield of cereals that are cultivated in the following year [5]. Due to the narrow C/N ratio, they mineralize in soil quite rapidly [16]. Some plants that are cultivated for green manure, e.g., the Fabaceae family, however, can cause a decrease in the yield of spring cereals, especially when applied during a water shortage [17,18]. According to Abdalla et al. [17], a legume–non-legume mixed catch crop rotation, which increases the grain yield and has no significant impact on the content of N in grain, should be used in order to avoid such negative impacts.

Besides its beneficial impact on the yield of successive cereal crops, legume catch crops also improve the quality of the grain parameters [19,20]. Such an impact is, however, highly dependent on the growing conditions of a plant. Taking into account the large variation in the physical, chemical and biological properties of soils in the eastern part of central Europe [21,22] as well as the weather conditions, which differ significantly in successive years [23–25], it is critical to develop plant-growing technologies that are optimal for specific conditions. The use of green manure is an important element of these technologies. The time and manner of introducing catch crop biomass into the soil plays an important role in its impact on the soil properties and the yield of the crops that are grown in the following year [4,6,10].

The aim of the study was to assess the soil chemical properties (macroelements) as well the composition of the grain and straw of spring barley that was cultivated on two different soil types (Luvisol and Phaeozem), which are affected by the time at which the catch crop is incorporated versus the control soil. We hypothesized that (1) the content of nutrients in both the soils and spring barley would be increased by field pea (FP) (*Pisum sativum* L.), which is cultivated as a catch crop compared to the control; (2) that the time that the catch crop is incorporated would differentiate the studied soil properties and spring barley features; and (3) that the influence of the catch crop on the soil and spring barley chemical properties might be dependent on the soil type.

2. Material and Methods

2.1. Site Description and Experimental Design

The research was carried out in two three-year-long (2009 to 2011) one-factor experiments, which was carried out in a randomized block design in four repetitions. One experiment was conducted on the farm located in Szadłowice (52°50′ N, 18°20′ E—WGS84), on a typical Phaeozem that, according to WRB, had been formed of a sandy loam (clay 6–12%, sand 55–72%, silt 18–35%). The second experiment was carried out at the experimental station in Mochełek (17°51′ E, 53°13′ N—WGS84) near Bydgoszcz (Figure 1) on typical Luvisol that had been formed of a sandy loam (clay 6%, sand 79%, silt 15%) [26].

Figure 1. Site of field experiments in the Kuyavian-Pomeranian voivodeship, Poland [27,28].

The method and time of catch crop incorporation were the experimental factors. The following levels of the factors were considered: the green mass of the catch crop that was incorporated in the autumn (A), the green mass that was incorporated in the spring after winter mulching (B) and the control soil, which was tilled without the application of the catch crop (C). The plot area was 250 m^2. Different management practices were used in each of the experimental plots. In plots A and B, field pea, which was used for green manure for spring barley that was to be cultivated the following year, was sown in August 2008, 2009 and 2010 (between the 5th and 9th of August in Mochełek and between the 7th and 13th of August in Szadłowice) (Table 1). Seeds of fodder cultivar 'Wiato' were sown at 150 kg ha^{-1} in row spacing of 15 cm, to a depth of 5 to 6 cm. No fertilization was used in the cultivation of the catch crop. Sowing of field pea was preceded by performing plowing to a depth of 15 cm. Moreover, the soil was tilled using a cultivator with a crumbler roller. The catch crops from plot A were harvested using a self-propelled mower between the 15th of October and 3rd of November (2008 to 2010). Then, the above-ground biomass was weighed and scattered on the soil surface of each plot. A plant sample of about 1 kg was collected from each plot in order to determine the content of the macronutrients (N, P, K and Ca) in the dry weight of the catch crops. The soil in treatments A and C was plowed in November and in spring. The soil was cultivated using a tilling set that consisted of a cultivator and a string roller, while the field pea in plot B was left to grow until winter. The biomass that was left on the soil surface after the winter was cut up and mixed with soil (at a depth of 10 to 12 cm) using a disc harrow in the following spring. The yield of the catch crop dry matter that had been incorporated into the soil was about 3.1 t ha^{-1} in Mochełek [3] and 2.7 t·ha^{-1} in Szadłowice [2]. The catch crop biomass accumulated a substantial amount of nitrogen and potassium but a lower amount of phosphorus (Table 2). A significantly higher concentration of nutrients accumulated in the catch crop biomass that had been cultivated on Luvisol (about 21%) than on the Phaeozem (Szadłowice).

Table 1. Sowing and harvesting times of catch crops.

Location	Year	Sowing Time	Harvesting Time	Number of the Growth Days
Mochełek (Luvisol)	2008	08.08.	21.10.	74
	2009	05.08.	28.10.	84
	2010	09.08.	15.10.	67
Szadłowice (Phaeosem)	2008	12.08.	03.11.	83
	2009	07.08.	20.10.	74
	2010	13.08.	19.10.	67

Table 2. The content of macroelements in catch crop biomass (kg·ha^{-1}).

Macroelement	2008	2009	2010
Mochełek (Luvisol)			
N	112.6	66.4	90.8
P	12.9	10.2	12.0
K	130.9	88.2	83.7
Ca	33.5	25.2	21.7
Szadłowice (Phaeosem)			
N	98.5	52.8	79.9
P	10.4	4.8	5.7
K	97.2	74.2	53.3
Ca	37.0	18.8	35.0

Spring barley (*Hordeum vulgare* L.), feed cultivar 'Tocada' has been used in the study. It was a new cultivar, characterized by above-average yield potential (60–67 dt·ha^{-1}), a high weight of 1000 grains (approximately 51 g) and an average resistance to plant diseases [29]. Spring barley was sown between the 31st of March and 8th of April of the following years (2009 to 2011). The spring barley was harvested in the first half of August. The amount of mineral fertilization that was used was based on the richness of the soil in nutrients and was applied in accordance with the requirements of spring barley. The soil was fertilized with phosphorus (P) at a dose of 26.2 kg·ha^{-1}, with potassium (K) at a dose of 66.4 kg·ha^{-1} and nitrogen (N) at a dose of 90 kg·ha^{-1}. Phosphorus, potassium and the first dose of N (45 kg·ha^{-1}) was applied before the spring barley was sown. The second dose of N fertilizer (45 kg·ha^{-1}) was applied during the shooting stage of spring barley (BBCH 31-32). The same management procedures were repeated each year during the entire study period (2009 to 2011).

The amount of precipitation during the growing season of field pea grown as a catch crop varied in both localities throughout the years of cultivation (Figure 2). In 2008 and 2010, very high amounts of precipitation were found in August. They ensured a good water supply for germinating pea seeds and contributed to the dynamic development of plants during the rosette formation period. In 2009, a significant shortage of precipitation was found in both locations in August and September.

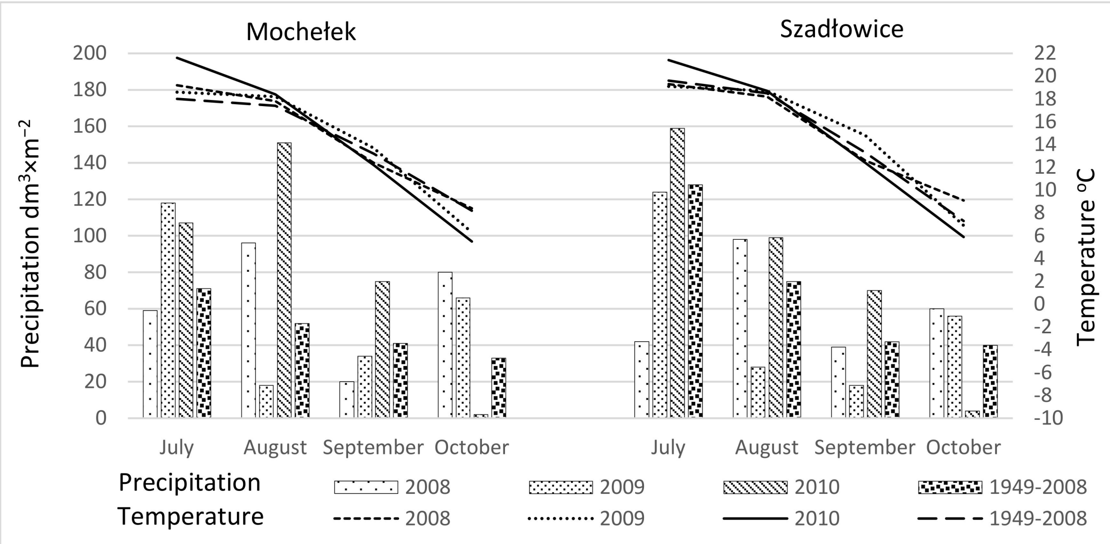

Figure 2. Precipitation and air temperature (2008 to 2010) during catch crop growth.

Air temperatures during this period were less volatile over the years (Figure 2). Relatively high average monthly temperatures were found in July and August. Both in Mochełek and in Szadłowice, the temperatures in the June and August were higher than the long-term average for this region. In September, temperatures were lower in 2008 and 2010, and in 2009, higher than the long-term averages. In 2008, relatively high temperatures in October had a positive impact on the growth and yield of the catch crop.

Weather conditions during the spring barley vegetation period were diversified in the years of the research (Figure 3). The amount of precipitation in both localities were relatively high throughout the whole study period. The distribution of rainfall was less favourable, which in none of the three years of the study was consistent with the demand for barley. In 2009, in Mochełek, a fairly good water supply of barley was found, in the period from the beginning of shooting to maturation. In 2010, there was a shortage of rainfall during the grain formation period (June), and in 2011, the rainfall deficit was noted during the tillering and shooting (April to May). In 2009, in Szadłowice, there was a shortage of rainfall during tillering and shooting, as well as good water supply in the period of grain formation and maturation. In 2010 and 2011, the major part of rainfall occurred only in the period of plant maturation.

Thermal conditions were favourable for the development of barley. Average air temperatures in April through all years of the research were higher than the long-term average for this region. This enabled the dynamic growth of plants during the emergence period. In 2010, air temperatures were relatively low in May and high in June.

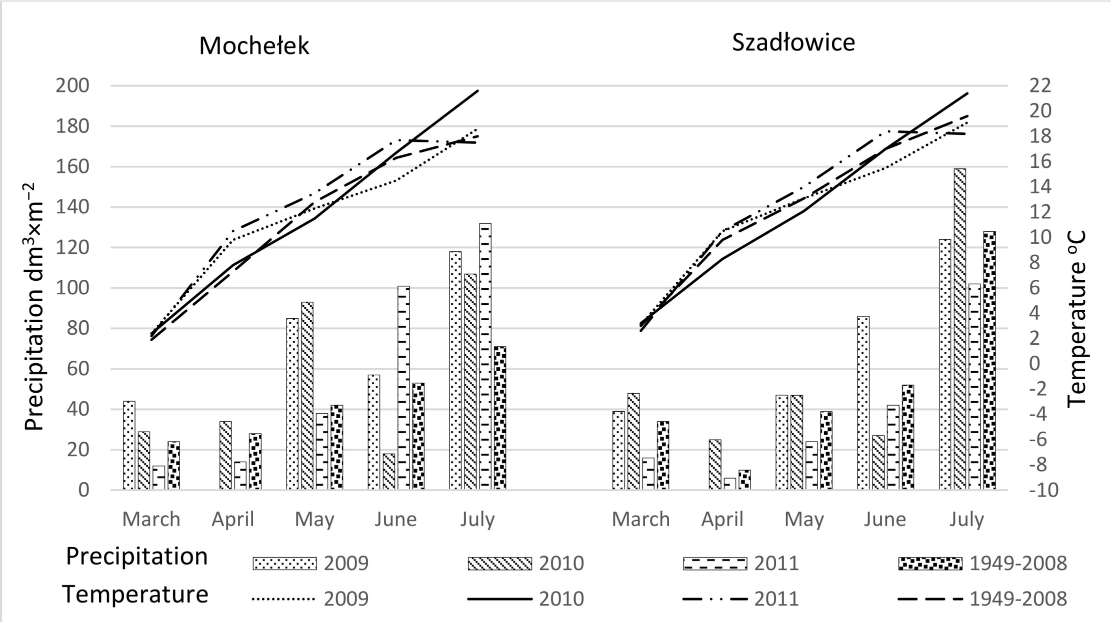

Figure 3. Precipitation and air temperature (2009 to 2011) during spring barley growth.

2.2. *Laboratory Analysis of the Soil and Spring Barley*

In spring, shortly before the mineral fertilizers were applied, and after the spring barley had been harvested, soil samples were collected in order to determine the effect of the catch crop on the soil chemical properties. Twelve soil samples were randomly collected from the upper soil layer (0 to 30 cm) from ech plot and bulked to provide one representative sample. Soil pH (1 M KCl) was measured using the potentiometric method in 1:2.5 soil: solution suspensions [30]. The total nitrogen (N_{TOT}) content was determined using the Kjeldahl method and organic carbon (C_{ORG}) content was determined using the dichromate oxidation procedure [31]. The available phosphorus and potassium content was determined using the Egner–Riehm (DL) method [32,33].

In the samples of spring barley grain and straw, the following chemical properties were determined: total nitrogen (Kjeldahl method) [34], phosphorus (vanadium-molybdenum method) [35], potassium and calcium (flame-photometric method) [36] and crude fiber using a modified method of Henneberg and Stohmann [37].

2.3. *Statistical Analysis*

The data of all of the studied properties were checked for normal distribution using the Shapiro–Wilk test. Since the data were normally distributed, we performed the statistical anlaysis with the untransformed data. The results from each year of the study were subjected to a one-factor analysis of variance (ANOVA) in a system of randomized blocks with four repetitions. Based on these analyses, ANOVA synthesis was performed for the three years of research. In the synthesis model, the year was a random effect and the method and time of the application of the catch crop was the constant (mixed model). When significant effects of a treatment were found, the post-hoc Tukey's HSD test was used to compare the means of the treatments. The means were considered to be significantly different at $p < 0.05$. The relationship between the concentration of the chemical properties were estimated using a correlation analysis based on Pearson's correlation coefficients ($p < 0.05$, $p < 0.01$ and $p < 0.001$).

3. Results

3.1. *Soil Chemical Properties*

The catch crop management significantly affected the soil chemical properties as well as the composition of the grain and straw of the spring barley that was cultivated in the following year (Table 3). The impact on the soil properties was generally greater in the case of the Phaeozems soil compared to Luvisol soil. However, the content of N_{TOT} and C_{ORG}, as well as that of pH_{KCl} were not dependent on the catch crop in any of the soils. Additionally, the interaction between the catch crop management and study years was found to be related to the soil chemical properties, especially in the case of the Phaeozems soil.

Table 3. Statistical differences (F-values and significance level) between means of variables by one-way ANOVA with factor catch crops management (d.f. = 2).

Research Material	Feature	Catch Crops Management (d.f. = 2)	Interactions: Catch Crops Management x Years (d.f. = 4)	Catch Crops Management (d.f. = 2)	Interactions: Catch Crops Management x Years (d.f. = 4)
		Mochełek (Luvisol)		Szadłowice (Phaeosem)	
Soil	pH_{Kcl}	2.789 NS	50.034 ***	1.977 NS	3.263 *
	NTot	0.881 NS	1.959 NS	1.00 NS	10.833 ***
	PAvail.	3.149 NS	1.815 NS	53.728 ***	31.846 ***
	KAvail.	9.794 **	18.256 ***	6.539 **	9.662 ***
	COrg.	0.059 NS	5.439 **	0.985 NS	3.833 *
Spring barley grain	N	127.37 ***	3.418 *	10.106 **	9.028 ***
	P	16.205 ***	5.138 **	0.681 NS	3.41 *
	K	6.831 **	20.945 ***	7.043 **	2.632 NS
	Ca	0.061 NS	0.495NS	2.875 NS	13.969 ***
	Crude fiber	0.680 NS	12.221 ***	2.06 NS	5.95 NS
Spring barley straw	N	11.704 ***	5.181 **	9.006 **	14.573 ***
	P	109.00 ***	68.333 ***	4.111 *	4.444 *
	K	9.394 **	5.655 **	10.177 **	51.478 ***
	Ca	35.733 ***	46.347 ***	1.90 NS	3.058 *
	Crude fiber	0.175 NS	3.337 *	1.704 NS	0.976 NS

d.f.—degree of freedom, NS—not significant; *—$p < 0.05$, **—$p < 0.01$, ***—$p < 0.001$.

Both of the studied soils differed substantially in their chemical properties (Tables 4–6). A slightly acidic (Luvisol) or alkaline (Phaeozem) reaction (exchangeable acidity—pH_{KCl}), which was determined before the spring barley was sown and after it was harvested, was not significantly affected by the time and the method of catch crop management. The concentration of C_{ORG} and N_{TOT} in the Phaeozem soil was almost 90% higher than in the Luvisol soil and was also not related to the method of catch crop management. There was a slightly higher content of C_{ORG} and N_{TOT} in the soil that was collected after the spring barley was harvested than before it was sown. The content of available P was about 43% higher in the Phaeozems soil than in the Luvisol soil and was significantly higher in the soil that had been taken from the field with the catch crop followed by the samples that had been taken from the control. In the soil from Mochełek, in turn, there were no significant differences in the P_{AVAL} content that were dependent on the catch crop management. The available form of K in spring was only 14% lower in the Luvisol soil than in the Phaeozems soil, whereas the content was significantly higher in the field on which the catch crop had been incorporated in the autumn (A) than in the B and C fields in both soils. The content of P and K was between 12% and 23% higher in the soil that was collected after the spring barley was harvested than before it was sown for both experimental sites.

Table 4. Exchangeable acidity and the content of macroelements in soil before catch crop sowing—means for 2008 to 2010.

Study Site	pH in KCl	Content (g kg^{-1} of Soil)			
		$N_{TOT.}$	$P_{AVAIL.}$	$K_{AVAIL.}$	$C_{ORG.}$
Mochełek (Luvisol)	6.07	0.78	0.104	0.234	8.77
Szadłowice (Phaeosem)	7.29	1.42	0.158	0.246	14.03

$N_{TOT.}$—total nitrogen, $P_{AVAIL.}$—available phosphorus, $K_{AVAIL.}$—available potassium, $C_{ORG.}$—organic carbon.

Table 5. Exchangeable acidity and the content of macroelements in soil before spring barley sowing—means for 2008 to 2010.

Catch Crop Management	pH in KCl	Content (g kg^{-1} of Soil)			
		$N_{TOT.}$	$P_{AVAIL.}$	$K_{AVAIL.}$	$C_{ORG.}$
Mochełek (Luvisol)					
A	5.61 a	0.720 a	0.087 a	0.212 a	8.48 a
B	5.61 a	0.723 a	0.089 a	0.206 b	8.51 a
C	5.66 a	0.707 a	0.085 a	0.205 b	8.52 a
Mean	5.63	0.717	0.087	0.208	8.50
$HSD_{0.05}$	ns	ns	ns	0.0048	ns
Szadłowice (Phaeosem)					
A	7.57 a	1.40 a	0.122 b	0.241 a	16.1 a
B	7.58 a	1.41 a	0.155 a	0.238 ab	16.0 a
C	7.59 a	1.41 a	0.093 c	0.231 b	16.2 a
Mean	7.58	1.41	0.123	0.237	16.1
$HSD_{0.05}$	ns	ns	0.0017	0.0082	ns

$N_{TOT.}$—total nitrogen, $P_{AVAIL.}$—available phosphorus, $K_{AVAIL.}$—available potassium, $C_{ORG.}$—organic carbon. A—catch crop incorporated in autumn, B—catch crop incorporated in spring, C—control (without a catch crop), without a catch crop. Means marked with different letters within particular columns are significantly different at 0.05 significance level, ns—non-significant differences.

Table 6. Exchangeable acidity and the content of macroelements in soil after spring barley harvesting—means for 2008 to 2010.

Catch Crop Management	pH in KCl	Content (g kg^{-1} of Soil)			
		$N_{TOT.}$	$P_{AVAIL.}$	$K_{AVAIL.}$	$C_{ORG.}$
Mochełek (Luvisol)					
A	5.67 a	0.789 a	0.096 a	0.258 ab	9.35 a
B	5.69 a	0.776 a	0.102 a	0.248 b	9.15 a
C	5.62 a	0.757 a	0.098 a	0.265 a	9.10 a
Mean	5.66	0.774	0.099	0.257	9.20
$HSD_{0.05}$	ns	ns	ns	0.0088	ns
Szadłowice (Phaeosem)					
A	7.56 a	1.47 a	0.151 b	0.266 a	16.6 a
B	7.56 a	1.47 a	0.174 a	0.265 a	16.5 a
C	7.58 a	1.45 b	0.107 c	0.267 a	16.4 a
Mean	7.57	1.46	0.144	0.266	16.5
$HSD_{0.05}$	ns	0.020	0.0021	ns	ns

$N_{TOT.}$—total nitrogen, $P_{AVAIL.}$—available phosphorus, $K_{AVAIL.}$—available potassium, $C_{ORG.}$—organic carbon A—catch crop incorporated in autumn, B—catch crop incorporated in spring, C—control (without a catch crop), without a catch crop. Means marked with different letters within particular columns are significantly different at 0.05 significance level, ns—non-significant differences.

3.2. Nutrients in the Grain and Straw of Spring Barley

The catch crops significantly affected the N content in the straw and grain of spring barley on both study sites (Table 3). Additionally, the content of phosphorus and potassium was usually associated with the catch crops (except for the P content in the Phaeozems soil). There was no significant influence of the catch crops on the content of crude fiber in the straw and grain of spring barley. However, in the Luvisol soil, the interaction between the method of catch crop management and the study years was associated with the content of crude fiber in the grain and straw.

Both of the studied soils differed in their nutrient content in the spring barley grain, which was affected by the catch crop management (Table 7). In Mochełek, spring barley that had been cultivated after the catch crop had a significantly higher N content in its grain than the crop that had been cultivated on the control plots (Table 7). Moreover, the P content in the spring barley grain that had been cultivated on the plots with the catch crops in Mochełek was significantly higher than in the control (Table 8). The spring barley that had been cultivated on the plots with the mulched field pea in Szadłowice (B) contained significantly less total N in the grain than the crop that had been grown in the control field. In the same location, the catch crop that had been incorporated into the soil in autumn (A) resulted in a significant increase of the K content in the grain of spring barley (Table 9). In turn, the content of this nutrient in the grain of spring barley that had been cultivated without the catch crop (C) in the Luvisol soil was significantly higher than that of the crop that had been grown in the field with mulched green manure (B). There was no significant influence of the catch crop management on the Ca and crude fiber content in the grain of spring barley.

Table 7. Content of nitrogen in spring barley grain (g kg^{-1}) depending on a catch crop management.

Catch Crop Management	2009	2010	2011	2009–2011
Mochełek (Luvisol)				
A	17.28 a	20.13 ab	16.41 a	17.94 a
B	17.29 a	20.56 a	16.19 a	18.01 a
C	15.98 a	18.38 b	14.22 b	16.19 b
Mean	16.85	19.69	15.61	17.38
$HSD_{0.05}$	ns	1.79	1.14	0.37
Szadłowice (Phaeosem)				
A	18.6 a	14.9 a	16.6 a	16.7 a
B	17.7 a	14.2 a	17.0 a	16.3 b
C	18.4 a	15.1 a	16.8 a	16.8 a
Mean	18.2	14.7	16.8	16.6
$HSD_{0.05}$	ns	ns	ns	0.30

A—catch crop incorporated in autumn, B—catch crop incorporated in spring, C—control (without a catch crop). Means marked with different letters within particular columns are significantly different at 0.05 significance level, ns—non-significant differences.

According to an analysis of the correlation, there was a significant, positive correlation coefficient between the P content in the spring barley grain and the yield of straw as well as between the content of K and Ca in the grain (Table 10). In turn, the content of Ca in the grain was significantly but negatively correlated to the content of crude fiber.

Table 8. Content of phosphorus (P) in spring barley grain (g kg^{-1}) depending on a catch crop management.

Catch Crop Management	2009	2010	2011	2009–2011
Mochełek (Luvisol)				
A	3.67 a	3.44 a	3.62 a	3.58 a
B	3.76 a	3.53 a	3.56 a	3.62 a
C	3.66 a	3.22 a	3.50 a	3.46 b
Mean	3.70	3.40	3.56	3.55
$HSD_{0.05}$	ns	ns	ns	0.79
Szadłowice (Phaeosem)				
A	3.94 a	2.98 a	1.98 a	2.96 a
B	4.02 a	2.85 a	1.97 a	2.95 a
C	3.98 a	2.93 a	2.00 a	2.97 a
Mean	3.98	2.92	1.98	2.96
$HSD_{0.05}$	ns	ns	ns	ns

A—catch crop incorporated in autumn, B—catch crop incorporated in spring, C—control (without a catch crop), without a catch crop. Means marked with different letters within particular columns are significantly different at 0.05 significance level, ns—non-significant differences.

Table 9. Content of potassium (K), calcium (Ca) and crude fiber in spring barley grain (g kg^{-1}) depending on a catch crop—means for 2009 to 2011.

Catch Crop Management	K	Ca	Crude Fibre
Mochełek (Luvisol)			
A	3.72 ab	0.419 a	52.17 a
B	3.65 b	0.424 a	52.29 a
C	3.75 a	0.415 a	52.92 a
Mean	3.71	0.420	52.46
$HSD_{0.05}$	0.079	ns	ns
Szadłowice (Phaeosem)			
A	3.59 a	0.339 a	50.83 a
B	3.52 ab	0.308 a	50.57 a
C	3.49 b	0.320 a	21.70 a
Mean	3.53	0.322	51.04
$HSD_{0.05}$	0.079	ns	ns

A—catch crop incorporated in autumn, B—catch crop incorporated in spring, C—control (without a catch crop). Means marked with different letters within particular columns are significantly different at 0.05 significance level, ns—non-significant differences.

Table 10. Simple correlation coefficients between yield and nutrient content in grain of spring barley in experimental period (2009 to 2011) (n = 18).

Property	Yield of Grain	Yield of Straw	Content of Nutrient in Grain			
			N	P	K	Ca
N	ns	Ns	x			
P	ns	0.48 *	ns	x		
K	ns	Ns	ns	ns	x	
Ca	ns	ns	ns	ns	0.69 **	x
Crude fibre	ns	ns	0.63 **	ns	ns	−0.73 ***

*—significant at $p < 0.05$; **—significant at $p < 0.01$; ***—significant at $p < 0.001$; ns—not significant.

The catch crop modified the chemical composition of the straw more than the grain (Tables 3 and 11). The influence of the catch crop on the total nitrogen content in the spring barley straw, which was (Mochełek and Szadłowice) higher in the plots with catch crop than in the control in both experiments, was especially strong. The concentration of P in the spring barley straw in both experiments was the highest in the field with the mulched green manure (B), and in Mochełek, the P content was significantly lower in the field with the catch crop that had been incorporated into the soil in the autumn (A) and the lowest in the control soil (C). In turn, in Szadłowice, the P content in the straw of spring barley that had been cultivated in the field in which the catch crop had been incorporated into the soil in the autumn (A) was significantly lower compared to the other sites. The effect of the catch crop on the K concentration in the straw was different and was associated with the soil type. In Mochełek (Luvisol), the highest K concentration was found in the straw of the spring barley that had been cultivated in the field in which the catch crop had been incorporated into the soil in the autumn (A), while in Szadłowice (Phaeozems), it was highest in the field that had been mulched with green manure (B). The application of the catch crop caused a decrease in Ca in the straw of the spring barley that was cultivated in Mochełek compared to the control, while in Szadłowice, the Ca content in the straw was not affected by this factor. The crude fiber in the straw and grain of spring barley was not significantly affected by the catch crop management at either of experiment locations.

Table 11. Content of macroelements and crude fiber in spring barley straw (g kg^{-1}) depending on a catch crop—means for 2009 to 2011.

Catch Crop Management	N	P	K	Ca	Crude Fibre
Mochełek (Luvisol)					
A	6.49 a	1.12 b	13.56 a	2.75 b	439.6 a
B	6.42 a	1.17 a	11.91 b	2.89 b	442.5 a
C	5.84 b	1.05 c	12.07 b	3.35 a	441.1 a
Mean	6.25	1.11	12.51	3.00	441.1
$HSD_{0.05}$	0.42	0.02	1.19	0.21	13.74
Szadłowice (Phaeosem)					
A	6.05 ab	0.72 b	13.3 b	3.35 a	453.3 a
B	6.20 a	0.75 a	14.3 a	3.34 a	456.0 a
C	5.76 b	0.74 a	12.9 b	3.42 a	450.2 a
Mean	6.00	0.74	13.5	3.37	454.5
$HSD_{0.05}$	0.30	0.02	0.89	ns	ns

A—catch crop plowed-in in autumn; B—catch crop as mulch; C—control, without a catch crop. Means marked with different letters within particular columns are significantly different at 0.05 significance level, ns—non-significant differences.

Table 12. Simple correlation coefficients between yield and nutrient content in straw of spring barley in experimental period (2009 to 2011) (n = 18).

Property	Yield of Grain	Yield of Straw	Content of Nutrient in Straw			
			N	P	K	Ca
N	ns	ns	x			
P	−0.47 *	ns	0.51 *	x		
K	0.75 ***	0.83 ***	0.68 **	ns	x	
Ca	−0.58	−0.80 ***	ns	ns	−0.81 ***	x
Crude fibre	ns	−0.57 *	−0.55 *	−0.71 **	−053 *	0.62 **

* significant at $p < 0.05$; **—significant at $p < 0.01$; ***—significant at $p < 0.001$; ns—not significant.

The N content in the straw of spring barley was significantly and positively correlated with P and K, while it was negative with the amount of crude fiber (Table 12). There was a highly significant and negative relationship between the K and Ca content in the straw of spring barley. The content of Ca in the straw was also negatively correlated with the yield of grain and straw, which, in turn, were positively associated with the content of K in the straw.

4. Discussion

4.1. Soil Properties

The method of catch crop management had a very limited impact on the chemical soil properties on both experiment sites (Tables 3–6). Neither the soil reaction nor the soil organic carbon and total nitrogen content was affected. In turn, the application of the catch crops significantly affected the concentration of the available K (on both sites) and the available P content (in Szadłowice). This positive effect on available forms of macronutrients (P and K) confirm the positive effect of catch crop to temporary accumulation and protection against the loss of easily accessible nutrients. According to Wanic et al. [3], catch crops can limit the migration of nutrients, including phosphorus, into deeper soil layers. In the study by Sharma et al. [38], a positive effect of cover crops has been obtained regarding the soil exchangeable bases' potassium, magnesium, calcium, sodium and micronutrients. In this case, the positive effect concerns especially the top layer of soil (0 to 5 cm in depth).

When planning the research, a significant impact of the method and time of biomass incorporation into the soil on the chemical properties of the soil was assumed. The authors expected that spring incorporation of catch crop biomass would let us better protect nutrients against its leaching from soil. This is especially important on light soils. In fact, the results presented in this manuscript partly confirm this positive impact of catch crops. Before the sowing of spring barley, a significantly higher content of available K was obtained when the catch crop was incorporated before winter compared to spring application. It may be explained by faster mineralization of biomass incorporated before winter. After harvest of spring barley, the highest content of available K was in the control treatment, where the yield of barley was significantly lower than after catch crops [5]. Thus, uptake of this nutrient from soil was less than in treatments with catch crops. However, no influence of catch crops and the time of biomass introduction into the soil on other soil chemical properties has been stated (the content of N_{TOT} and C_{ORG}, as well as pH_{KCl} value). This lack of change in soil reaction was in agreement with the authors' predictions and earlier data [39,40]. The application of the catch crop had no significant effect on the total N in the soil that was collected before the spring barley being sown, which was the result of the relatively low amount of this nutrient that had accumulated in the catch crop biomass. During the three years of the study, the mean accumulation of N in the catch crop biomass was 77.1 $kg \cdot ha^{-1}$ in Szadłowice and 89.9 $kg \cdot ha^{-1}$ in Mochełek. When the content of total soil N (1.41 $g \cdot kg^{-1}$ in Szadłowice and 0.72 $g \cdot kg^{-1}$ in Mochełek) and soil bulk density (1.65 $g \cdot cm^{-3}$ in Szadłowice and 1.62 $g \cdot cm^{-3}$ in Mochełek) were assessed, the N content in the soil layer of 30 cm was 6979 kg in Szadłowice and 3499 kg in Mochełek. That is why the amount of N that had been incorporated into the soil to which the catch crops had been applied only represented 1.1% and 2.6% of the total stock of N that had accumulated in the plowed layer of the soil in Szadłowice and Mochełek, respectively. Therefore, the amount of N that was added to the soil with catch crop biomass was not sufficient to achieve a significant increase of this nutrient in the soil.

The results that have been presented in this respect to date are ambiguous. In the study of Arlauskiené and Maikšténiené [41], there was no effect of the application of catch crops on the soil total N content, while Navas et al. [42] found a highly significant and positive effect of catch crops on this nutrient. As was presented by Berntsen at al. [43], catch crop biomass that had been incorporated into the soil in the spring resulted in a significant increase in the organic N content in the soil. A study carried out by Wilczewski et al. [5] showed a highly significant effect of the catch crops on the soil mineral N for both the autumn and spring incorporation of biomass into the soil. The slight effect of the application of the catch crops on the concentration of total N and organic C might be due to the relatively short-term treatments that had been applied on different sections of a field in specific years. Therefore, it was not possible to accumulate the mineral nutrients in the soil in the following years. In fact, the effect of green manure or tillage that favors the accumulation of organic matter on the physical and chemical properties of soil is usually observed after they have been applied over a long period of time in the same field [44,45]. Three [46] and eight years [47] of the application of organic matter in the form of different catch crops did not result in any differences in the organic carbon content.

A single incorporation of catch crop biomass into the soil was usually sufficient to increase the content of available forms of P and K but was not enough to increase the content of total N and organic C in soil. Piotrowska-Długosz and Wilczewski [10] showed a significant effect of a catch crop, both when incorporated in the autumn or mixed with the soil in the spring, on the content of the soil microbial biomass carbon, which persisted throughout the entire growing period of spring barley. Therefore, despite the lack of an effect of the catch crop on the total N or organic C, they did have a considerable effect on the soil biological activity. Moreover, as has been stated in another paper from these experiments, a single incorporation of catch crop biomass into the soil was sufficient to positively affect the yield of spring barley in Luvisol [5]. However, there was no influence of catch crops on the soil concentration of available forms of P and K on Luvisol. This may be connected with the so-called "dilution effect". Another situation was on Phaeosem, where catch crops had no effect on the spring barley yield [4], whereas it significantly influenced the concentration of available forms of P.

4.2. Grain and Straw of Spring Barley

The effect of the catch crop on the N content in the grain of spring barley varied at both experiment sites and was generally positive in the Luvisol (Mochelek) soil and negative or neutral in the Phaeozems (Szadłowice) soil (Table 7). These differences could have been caused by the greater amount of nitrogen (Table 2) that was introduced into the soil with catch crop biomass in Mochełek, along with a lower (than in Szadłowice) amount of this nutrient in soil (Table 4). On the other hand, the better soil conditions in Szadłowice resulted in a higher (23.9%) spring barley yield at this location [16,17]. In the study of Janzen and Schaalje [48], spring barley took up 32% of the nitrogen that had been incorporated into the soil with biomass of Fabaceae during the whole growth period, whereas 24% was taken up within 45 days after the spring barley had been sown. Thus, the main uptake of nitrogen from the Fabaceae catch crop biomass occurs in the vegetative development of the plants, and only a small part is taken up during grain formation. This is due to the narrow C:N ratio in the biomass of these plants, which results in a fast mineralization [16]. That is why the green manure from the Fabaceae plants mainly affects the grain and straw yield of panicle cereals. A relatively large variation in the N content in barley grain in particular years of the study was related to the varied water supply. In the years characterized by a high amount of rainfall in June to July (Szadłowice 2010 and Mochełek 2011), the N content in barley grain was lower than in other years in a given location.

The negative effect of the application of the catch crop on the content of K in the grain of spring barley in Mochełek might have been caused by its positive effect on the yield of barley on this site [5]. It can be supposed that the so-called "dilution of the nutrient" occurred in the greater mass of the yield. In Szadłowice, where the grain yield of spring barley was not associated with the method of catch crop management [4], there was a significantly higher concentration of K in the grain of the barley that had been cultivated in the fields on which the catch crop biomass was incorporated in the autumn compared to the control. However, the effect was relatively small, and no significant relationship was found between the grain yield and the concentration of the nutrients.

Such relationships were observed in relation to the composition of barley straw to a greater extent, which was in agreement with the data that was presented by Janzen and Schaalje [48], who indicated that spring barley mainly took up the nutrients that were released during the mineralization of the Fabaceae catch crop biomass in the early vegetation period when the vegetative parts of the plants are formed. This favored the positive effect of the catch crop on the nitrogen content in the straw of spring barley that had been cultivated on both sites and increased the P content in the straw of spring barley that had been grown in Mochełek.

5. Conclusions

The effect of field pea that is cultivated for green manure on the content of the nutrients in the grain and straw of spring barley was associated with the properties of soil types that were used in the experiment. In the Luvisol soil, the application of the catch crop increased the nitrogen and phosphorus content in the grain and straw of the spring barley regardless of the method and time of its incorporation into the soil. However, the effect of the application of the catch crop in the Phaeozems soil was less obvious. On this soil, only the autumn incorporation of the biomass into the soil contributed to a significant increase of K in the grain of spring barley. The other nutrient content in spring barley grains were not affected by the catch crop. The results of this study show that catch crops grown for green manure may be an important element improving the conditions of barley growth, especially in the conditions of soils that are less rich in humus and minerals.

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